

Measurement of b -baryons with the CDF II detector

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Abstract. We report the observation of new bottom baryon states. The most recent result is the observation of the baryon Ξ_b^- through the decay $\Xi_b^- \rightarrow J/\psi \Xi^-$. The significance of the signal corresponds to 7.7σ and the Ξ_b^- mass is measured to be $5792.9 \pm 2.5(\text{stat.}) \pm 1.7(\text{syst.}) \text{ MeV}/c^2$. In addition we observe four resonances in the $\Lambda_b^0 \pi^\pm$ spectra, consistent with the bottom baryons $\Sigma_b^{(*)\pm}$. All observations are in agreement with theoretical expectations.

1. Introduction

The quark model has been very successful in describing the spectroscopy of hadrons, both for light hadrons as well as for hadrons with heavy quarks. The spectroscopy of heavy baryons (or mesons) provides an interesting laboratory for understanding the theory of strong interactions, Quantum Chromodynamics (QCD), in a regime where perturbation calculations cannot be applied. In effective models of the heavy hadron systems, like heavy quark effective theory (HQET) [1], the degrees of freedoms of the heavy quark are considered decoupled from those of the light quarks, so that a heavy baryon system can be modeled in a similar way as the helium atom is modeled.

Experimental results in the b -baryon sector have so far been limited to one single state, the Λ_b^0 with quark content (udb). In these proceedings we present the observation and the mass measurement of further b -baryon states: the Ξ_b^- state [2] and the $\Sigma_b^{(*)\pm}$ states [3].

2. Observation of the bottom baryon Ξ_b^-

The baryon with quark content (dsb) and spin $S = \frac{1}{2}$ is labelled Ξ_b^- in the baryon naming scheme. Using 1.9 fb^{-1} of data collected with the CDF II detector, Ξ_b^- candidates are reconstructed in the decay chain $\Xi_b^- \rightarrow J/\psi \Xi^-$, where $J/\psi \rightarrow \mu^+ \mu^-$, $\Xi^- \rightarrow \Lambda \pi^-$, and $\Lambda \rightarrow p \pi^-$.

An important feature of the analysis is that the intermediate Ξ^- baryon can be tracked by precision measurements in the silicon layers of the CDF II detector, since the Ξ^- is a charged and long-lived particle. This significantly improves the secondary vertex resolution and strongly helps to suppress background of random $\Lambda \pi^-$ combinations.

It is expected that the mass splitting between the b -baryons Λ_b and Ξ_b is similar to that between the c -baryons Λ_c and Ξ_c , leading to an expected value of $\sim 5.8 \text{ GeV}/c^2$ for the Ξ_b mass [5, 6]. Furthermore the decay properties should be dominated by the weak transition of the b -quark, so that the decay of the Ξ_b should show similarities to those of other weakly decaying b -hadrons. The last fact is exploited to choose an unbiased selection procedure of the Ξ_b^- -candidates. A

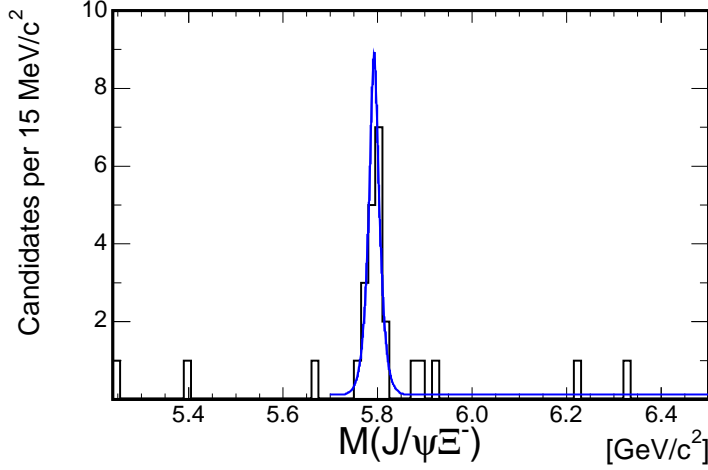


Figure 1. The mass distribution of Ξ_b^- candidates after cut optimization. Also shown is the projection of the used fit function, yielding 17.5 ± 4.3 Ξ_b^- candidates.

sample of $\sim 30,000$ $B^+ \rightarrow J/\psi K^+$ decays, which are kinematically similar to the desired $\Xi_b^- \rightarrow J/\psi \Xi^-$ decays, is used to optimize the selection. The result is shown in Fig. 1. A clear signal is visible and its mass is measured to be $5792.9 \pm 2.5(\text{stat.}) \pm 1.7(\text{syst.})$ MeV/c². This is in good agreement with a recent measurement from D0 [4] and with theory predictions. The probability to observe a background fluctuation of this size is evaluated to be 6.6×10^{-15} , corresponding to a signal significance of 7.7σ .

3. Observation of the bottom baryon states Σ_b^\pm and $\Sigma_b^{\pm*}$

The charged Σ_b baryon states have quark content (uub) and (ddb). In HQET, the light diquark system, treated separately from the b -quark, has isospin $I = 1$ and spin $j = 1$. Together with the b -quark the light quarks form the isospin triplet Σ_b^+ , Σ_b^0 , Σ_b^- (the corresponding isospin singlet baryon state is the Λ_b^0). The spin $j = 1$ of the diquark system can couple with that of the b -quark to either $J = \frac{1}{2}$ or $J = \frac{3}{2}$. The triplet states with $J = \frac{1}{2}$ form the ground state Σ_b baryons, while the states with $J = \frac{3}{2}$ are labelled Σ_b^* . The range of theoretical predictions for the expected masses is shown in Tab. 1.

Table 1. Mass and width predictions for the $\Sigma_b^{\pm(*)}$. See [3] for an extensive list of references.

Quantity	(MeV/c ²)
$m(\Sigma_b) - m(\Lambda_b^0)$	180 – 210
$m(\Sigma_b^*) - m(\Sigma_b)$	10 – 40
$m(\Sigma_b^-) - m(\Sigma_b^+)$	5 – 7
$\Gamma(\Sigma_b), \Gamma(\Sigma_b^*)$	$\sim 8, \sim 15$

Table 2. Measured masses for the $\Sigma_b^{\pm(*)}$ states, calculated from the Q values with $m(\Lambda_b^0)$ from [7].

State	Mass (MeV/c ²)
Σ_b^+	$5807.8^{+2.0}_{-2.2}(\text{stat.}) \pm 1.7(\text{syst.})$
Σ_b^-	$5815.2^{+1.0}_{-1.0}(\text{stat.}) \pm 1.7(\text{syst.})$
Σ_b^{*+}	$5829.0^{+1.6}_{-1.8}(\text{stat.})^{+1.7}_{-1.8}(\text{syst.})$
Σ_b^{*-}	$5836.4^{+2.0}_{-2.0}(\text{stat.})^{+1.8}_{-1.7}(\text{syst.})$

The search is based on 1.1 fb^{-1} of data using the decay mode $\Sigma_b^{\pm(*)} \rightarrow \Lambda_b^0 \pi^\pm$, where $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and $\Lambda_c^+ \rightarrow p K^- \pi^+$. A sample with ~ 3200 Λ_b^0 baryons is combined with charged pion tracks to obtain the $\Sigma_b^{\pm(*)}$ candidates. The search is performed in the variable $Q = m(\Lambda_b^0 \pi^\pm) - m(\Lambda_b^0) - m(\pi^\pm)$ to minimize the contribution of the mass resolution of each Λ_b^0 candidate. During the cut optimization process and the determination of the background contributions, the signal region, estimated from theory predictions, is kept blinded (see Fig. 2).

After unblinding the spectrum, an excess is observed in the signal region. The $\Sigma_b^{-(*)}$ and $\Sigma_b^{+(*)}$ spectra are fitted simultaneously with an unbinned maximum likelihood fit, where $m(\Sigma_b^{+*}) - m(\Sigma_b^+)$ is constrained to be identical to $m(\Sigma_b^{-(*)} - m(\Sigma_b^-)$. The projection of the fit result is shown in Fig. 3 and the measured $\Sigma_b^{\pm(*)}$ masses are listed in Tab. 2. The null hypothesis (no signal) is excluded by more than five standard deviations and, except for the Σ_b^+ signal, each single signal has a significance exceeding three standard deviations.

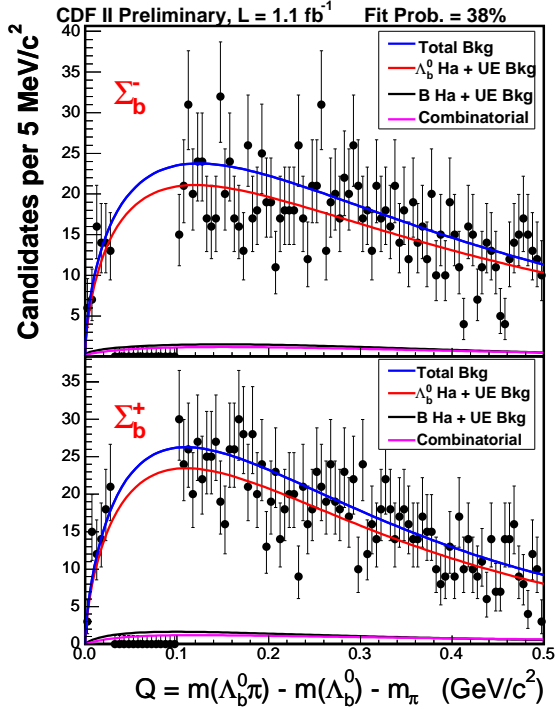


Figure 2. The Q spectra and the background estimation of the $\Sigma_b^{-(*)}$ (top figure) and $\Sigma_b^{+(*)}$ (bottom figure) candidates after cut optimization.

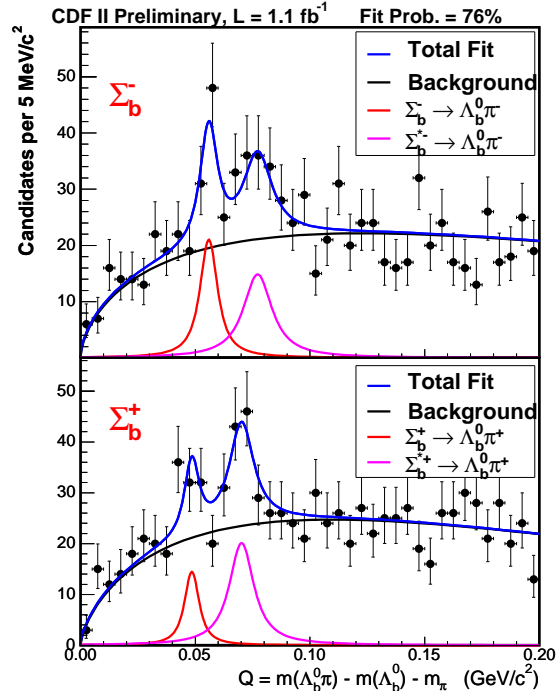


Figure 3. The fit to the Q spectra after unblinding the signal region.

4. Conclusions

In summary, the CDF Collaboration has observed both the four lowest-lying charged $\Sigma_b^{\pm(*)}$ baryons as well as the negatively charged Ξ_b^- baryon. All results are in good agreement with theoretical predictions.

References

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